Investigative Case-Based Learning: Teaching Scientifically While Connecting Science to Society

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The purpose of the NSF-funded LifeLines OnLine project (CCLI-EMD 9952525) was to develop and disseminate new, investigative case-based curriculum modules and pedagogies for introductory biology; to prepare a cadre of faculty in the development and use of these modules; and to examine the effectiveness of the modules in college biology classrooms. Participating faculty produced 31 case modules. Of this faculty, 90% implemented cases in a course, over 50% gave a presentation on cases and Investigative Case-Based Learning (ICBL), and 10% published a paper about their work. Field-testing results were overwhelmingly positive.

Figure 1. LifeLines website containing participant-developed cases, implementation resources, and links to related sites.

These are extraordinary results from a curriculum materials development project. In the recent article "Scientific Teaching," Handlesman et al. (1) identified the LifeLines project (Figure 1) as an example of research-based pedagogy shown to be effective in college science classes.

ICBL (2–4) is the teaching approach at the core of the LifeLines OnLine project. ICBL uses cases set in realistic contexts as the starting place for developing student-centered science investigations. Originally designed for adult students taking biology as a general education requirement in 2-year colleges, the ICBL approach has been demonstrated to be applicable in STEM disciplines and across institutional types.

Rationale for ICBL

Since the 1960s, cases have been used for teaching basic medical sciences (5,6) in a model called Problem-Based Learning (PBL) (7). PBL gives students opportunities to direct their own learning as they explore the science underlying realistically complex situations. Students work collaboratively to identify issues, to frame questions of interest to them, and to identify additional information in answer to their questions. The medical model of PBL has been successfully adapted for both secondary (8) and undergraduate science education (e.g., the University of Delaware website on PBL, http://www.udel.edu/pbl).

ICBL is a variant of PBL that aligns problem-based learning methods with the investigative approaches found in the software, tools, and resources of the BioQUEST Curriculum Consortium. Not only do students analyze a socially relevant case and gather more information, but they also engage in developing and testing their hypotheses. They use a variety of methods and resources, such as traditional laboratory and field techniques, software simulations and models, data sets, Internet-based tools, and information retrieval methods. Finally, the students produce materials that can be used to persuade others of their findings.

ICBL was developed as one response to reports calling for reform in undergraduate STEM education (e.g., 9). Called for in these reports is not just more science, but science that is more inquiry based. "Build into every course inquiry, the processes of science, a knowledge of what practitioners do, and the excitement of cutting edge research" (9, p. 53). Also called for is that science be explicitly connected to everyday life. "Start with the student's experience...and relate the subject matter to things the student already knows" (9, pp. 65–66).

By developing instruction around realistically complex cases set outside the classroom and research laboratory, students learn the science in the context of things they already know. This makes it easier to see the connections between the underlying abstract science concepts and their applications in everyday things. For example, a case might be about people drinking coffee at their home by a river who read in the newspaper that the fish harvest from the river is decreasing. This case might be used in invertebrate zoology, ecology, or general biology. Rich societal contexts are both multidisciplinary and motivational. They are written about people grappling with issues that scientific inquiry can help illuminate. Cases provide a meaningful context for learning, with a memorable anchoring experience on which to situate further learning (10).

The teaching strategies used in ICBL are based on research on learning. First is the principle that learners construct new knowledge based on what they already know. Learners come "to formal education with a range of prior knowledge, skills, beliefs, and concepts. This affects what learners notice, how they reason and solve problems, and how they remember" (11, p. 10). Investigative cases enable students to use their prior knowledge related to the case and their own interests to develop meaningful science questions for further study and investigation.

Second, during the analysis of the case, students work collaboratively to identify what they already know about the case, as well as what else they need to know. In this step, students develop and use metacognitive skills (a self-awareness of their learning) shown to enhance performance (11).

The third principle is that people have idiosyncratic understandings of many science concepts (research on this is summarized by Bransford et al. [11]). By discussing their ideas with others, students begin to become aware of the value of their peers' ideas. It can also alert the students to the existence of misconceptions in themselves. Identifying one's own "wrong" ideas is a key step in rooting them out so that more accurate understandings can be developed.

Learning through PBL has shown that long-term retention of content is significantly increased, although initial subject matter achievement may be the same or somewhat less than in traditional lecture-based instruction (e.g., 8,12–14). In addition, students who used PBL are also better at collaboration and information gathering and have better interpersonal skills—all attributes valued in the workplace and asked for by reformers. "Devise and use pedagogy that develops skills for communications, teamwork, critical thinking, and lifelong learning in each student..." (9, p. iii).

Using Investigative Cases for Teaching and Learning

As we developed ICBL, we found the BioQUEST 3's approach (15) to be helpful as a framework for instruction. The 3 Ps—problem posing, problem-solving, and peer persuasion—are correlated with actions taken by scientists engaged in scientific problem-solving. Practicing scientists define problems, develop methodologies and strategies to investigate those problems, and present their findings to persuade other members of their community of the reasonableness of their findings. Students who learn with ICBL use a similar three-phase approach that is outlined below.

Phase I. Problem posing: analyzing a case

A. Introduce the case: Students see the case for the first time in class and read it together.
B. Recognize potential issues and major topics: Carry out a brief large-group discussion identifying the content of the case.
C. Pose specific questions via Know/Need to Know analysis: Introduce a formal, but brief, process of collaborative group discussion identifying prior knowledge and outstanding questions.

Phase II. Problem-solving: investigating the questions

A. Obtain additional references/resources: These may be supplied or students can search on their own.
B. Define problems further by sharing views and concerns: Students discuss what they've learned and refine their questions.
C. Design and conduct scientific investigations: This stage may follow directly from the above discussions or may follow a lab session in which students learn critical techniques for investigating their questions.

Phase III. Peer persuasion: supporting methods and reasoning

A. Produce materials that support understanding of the conclusions: Traditionally, this would be a lab report, but other possible products might include an informational pamphlet targeted to a population in the case; posters, videos, consulting reports, graphics, designs for new technology, newspaper stories or editorials, or new case studies.
B. Evaluation of what was learned: It is important to evaluate both process and subject matter content. Did students reorganize their material, did they manage information appropriately, and did they work well in groups?

A detailed explanation of each stage of the ICBL process using an environmental microbiology case is available online at http://serc.carleton.edu/introgeo/icbl/index.html.

Using ICBL for a Variety of Instructional Purposes

It might be appropriate to some learning goals to use all three phases of an ICBL module. Indeed, many of our participants did just that as they implemented their cases in their courses. These faculty used an average of three class sessions, including a lab, for their module. Students also worked outside of class.

For other learning goals, the strategies used in ICBL might be used separately. For example, a faculty member might choose to use only the case strategies listed in Phase I, problem posing, as a way to assess students' prior knowledge on a topic and to help students structure their learning of that topic.

Alternatively, by focusing primarily on the strategies in Phase II, problem-solving, an investigative case can be used to provide a meaningful context for a laboratory-, field-, or computer-based activity that will be taught later. Additionally, if students are to develop a term paper (an informational rather than inquiry research project), the strategies in both Phases I and II are useful.

Strategies in Phase III, peer persuasion, in combination with case analysis, are useful if a case is being introduced as a basis for an ethics paper, class debate, or issues briefing paper. Here, the students would use the case to stimulate literature-based inquiry.

All three phases of ICBL can be used with a single case, but each can stand alone as well. We have seen investigative cases being used in science classrooms to accomplish a variety of learning goals, such as the following:

- Provide enriched content to be assessed in exams
- Address multicultural perspectives
- Integrate historical incidents
- Introduce problem scenarios that benefit from modeling and simulation
- Assess data interpretation skills
- Introduce experimental design

LifeLines Model of Faculty Development

We developed a model of faculty development for the 4-day summer institutes that has several components and strategies to address multiple goals. We expected the faculty to learn how to use case teaching strategies, to master at least one piece of simulation or modeling software, to experience collaborative group work, to use peer persuasion to convince others of their findings, to learn or further develop skills in using educational technologies, to create a new ICBL module for one of their courses, and to plan how they would implement the module and assess the students.

To accomplish these goals in such a short time, we needed excellent resources. Facilities included comfortable residence rooms and meeting rooms, and computer labs were conveniently located in a well-equipped dormitory on one of our campuses. We also needed a high faculty-to-participant ratio to provide the just-in-time teaching of technology skills and for helping individuals conceptualize their modules. Our staff included people who had implemented ICBL already, as well as a range of technical expertise. A third resource was software and expendables. We provided the BioQUEST Library to each participant, located many web-based tools, and made available plenty of materials for producing posters, for brainstorming, for planning, and for saving files. Finally, being able to support the participants monetarily was an important key to the success of the NSF summer workshops.

The workshops begin with a case. We ask the faculty to be learners, but at their current levels of expertise. They are given a case and a piece of software to use to investigate the case. By collaboratively working through the phases of ICBL from a learner's perspective, the faculty see the techniques as used by experienced teachers while simultaneously feeling what it is like to learn with a case. It is essential to do this step, but is equally important to keep it brief—less than one day.

For the remainder of the workshop, participants think about using a case module from their perspective. They work in groups in short sessions to discuss possible ideas, write preliminary cases, and develop implementation plans. Peer coaching and review is an important part of this model, which takes advantage of the variety of expertise present in the group.

Each participant (or team of two participants) then constructs their ICBL module. The computer lab is heavily used for this, and workshop staff are available to answer questions or help with individual requests. Optional sessions for demonstrating software or teaching how to use PowerPoint or make a website are offered or taught on demand. This individualized assistance is key support while participants develop a product that is ready to go and is necessitated by the wide range of incoming skill with educational technology. The availability of individualized instruction was an element receiving highest marks in post-workshop evaluations.

Field-testing of the ICBL modules is supported in several ways. First, the faculty members receive a stipend upon submission of their field-testing results. Second, we made forms for evaluating the cases available on the web. Third, after the workshop was over, the participants had access via phone or email throughout the year.

To evaluate workshop components, interviews were conducted during field-testing by our external evaluator, who also conducted surveys at the end of the workshops. We used the results of these evaluations formatively and changed our workshops in response to them.

Major Contributions of the LifeLines ICBL Project

The LifeLines project has developed, and continues to maintain through an agreement with the BioQUEST Curriculum Consortium, a website that serves as a portal to resources for ICBL. Available online are 31 cases developed by faculty attending ICBL workshops (funded by our NSF grant) and 34 cases developed at invited workshops (funded externally by other projects and organizations).

The website was subjected to formative review and testing by faculty users and staff. The site offers expanded support for ICBL users via contact information for participants and staff, current calendar and event archives, and links to other multidisciplinary case projects. Support also includes extensive faculty development resources for using ICBL, a student guide to using cases, and field-testing materials for both students and instructors.

Our most recent improvements support case authoring and web publishing for our participants both during and after the workshop. Prototype workshop pages that show data-driven project submission and editing tools with image and data file uploading functions are available for review at http://bioquest.org/lifelines/prism/resources.

The LifeLines project has fostered the development of a cadre of biology faculty who are actively using new pedagogies, creating new modules, extending ICBL to online and distance learning, and telling other faculty about their work. Over half of the funded participants have made presentations within departmental, institutional, or organizational meetings. Four have published cases in books such as *Microbes Count: Problem Posing, Problem-Solving and Peer Persuasion in Microbiology.* (16). This result is especially notable given the low level of support for professional development offered to most 2-year college faculty. Similar results have come from LifeLines collaborations with the Center for Science Education at Emory University, with participation by 45 college faculty, post-docs, and graduate students from 2- and 4-year colleges, including the Atlanta University Center historically black colleges. From the 2002 workshop alone (22 participants; see Figure 2), there have been five presentations at conferences, a spin-off workshop at another university, and incorporation of cases into eight courses (Dr. Pat Marsteller, personal communication).

Figure 2. Participants from the summer 2002 workshop, Implementing Problem-Solving Strategies: Investigative Cases for Biology and Chemistry, *held at Emory University.*

A third major contribution from the LifeLines project is the faculty development resources that we have created, which include background and rationale for ICBL, how to write cases and generate ideas for cases, notes on implementation, notes for students, a clear example of how to teach with cases, links to other sites with cases on the web, and how to share cases. All these materials enable interested faculty to explore the ICBL approaches and to support implementation of their work. This is a uniquely robust resource among websites on PBL or case-based learning.

The LifeLines OnLine project has far exceeded its proposed goals, both in terms of number of faculty reached (135 proposed in three workshops and 9 presentations versus 435 faculty in 14 workshops and 23 presentations) and in number of new curriculum modules (8 proposed versus 65 completed). Nine papers featuring ICBL and LifeLines OnLine have been published. A casebook to accompany a major introductory biology textbook is in press. In addition to invitations to present on ICBL from organizations such as the American Society for Microbiology (ASM), Association of College and University Biology Educators (ACUBE), Botanical Society of America (BSA), American Institute of Biological Sciences (AIBS), and a variety of colleges and universities, we conducted an NSF Chautauqua short course on ICBL in July 2004 and will conduct another in 2005. We think ICBL is a very successful strategy for creating knowledgeable consumers of science as well as for promoting science as a course of study. Our experience is that faculty value teaching with cases as they witness their students increased response to solving realistic problems with scientific reasoning and inquiry.

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